Dispersion and Control of Radio and Bio Aerosols

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Definitions

- Dispersion
  - dispersing or being dispersed
  - The breaking up of light into its components
  - A colloidal system with its dispersed particles and the medium in which these are suspended
- Dispersal
  - Dispensing or being dispersed
  - distribution

Relative Effects of NBC Weapons

Parameter	Nuclear	Chemical	Biological
sq miles	75-100	100	34,000
Morbidity	98%	30%	35-75
Residual	6 months 1000 sq. m.	3-36 hrs	Epidemic Spreads all over
Time	seconds	30 secs	few to 14 days
Prop. Damage	30 sq miles	undamaged	undamaged

Means of dispersion

- Air
- Water
- Ingestion
- Physical Contact, etc.

- We will focus on the airborne route

Primary Aerosol

- Particles with 1 to 5 micrometer diameter are called the primary aerosol
- The primary aerosol behaves like a gas
- A person becomes infected because he or she is breathing at a rate of 10 to 20 liters of air a minute.

$1\,\text{Å} = 10^{-10}\,m = 10^{-8}\,cm = 10^{-4}\,\mu m$, $1\,\mu m = 10^{-6}\,m = 10^{-4}\,cm$, $1\,nm = 10^{-9}\,m = 10\,\text{Å}$

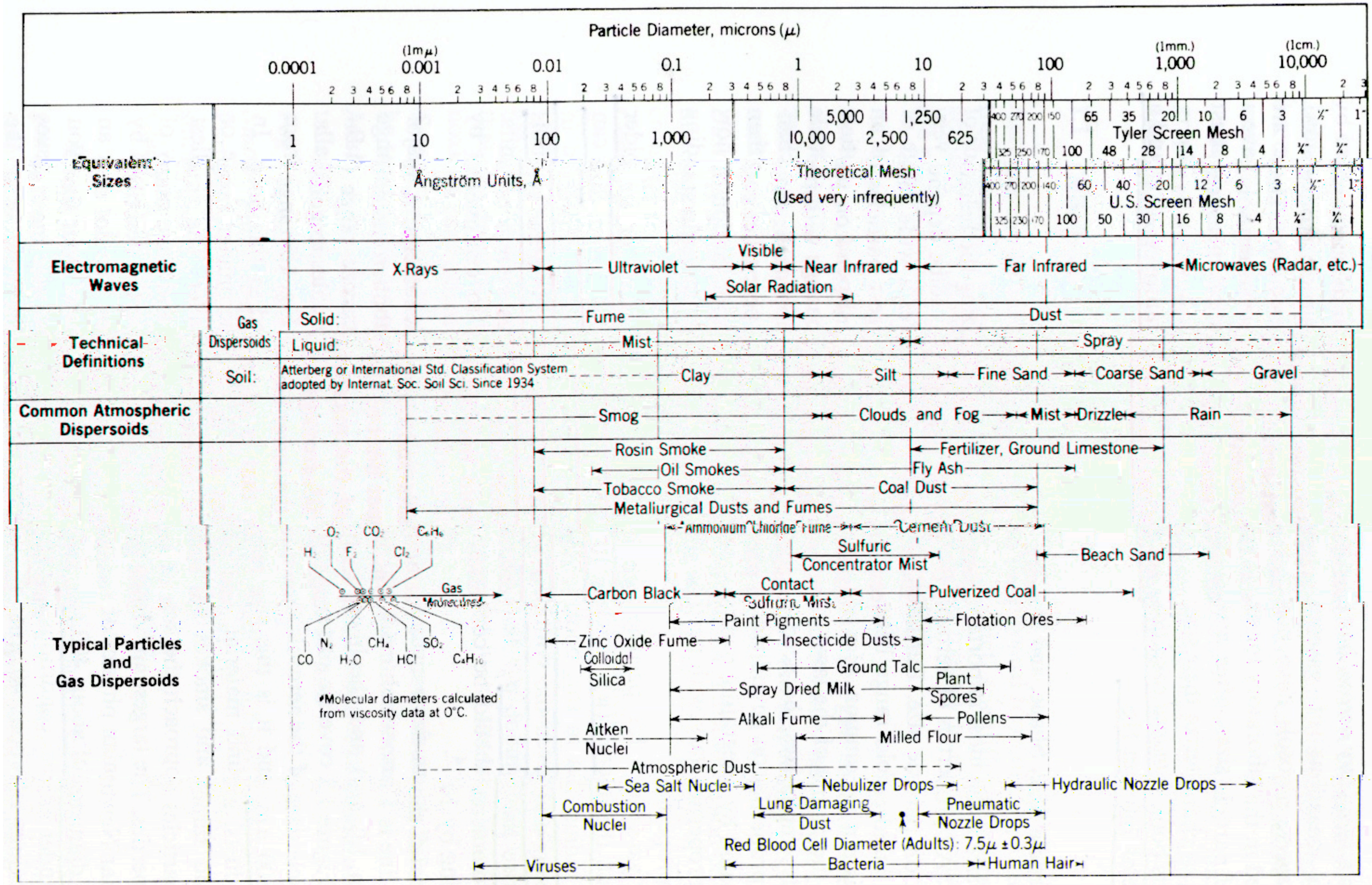
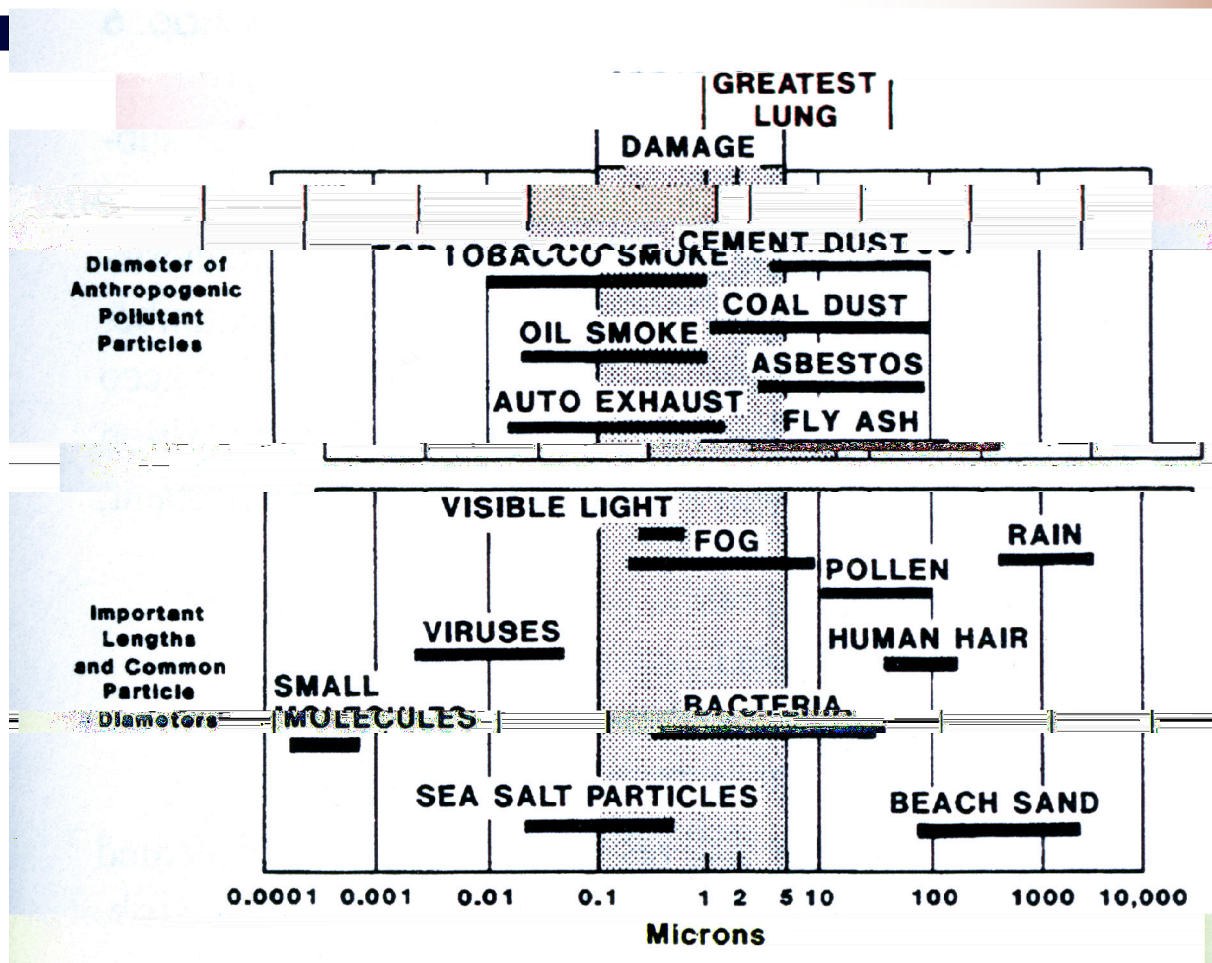


Figure 1.5 Particle size ranges for aerosols. Reprinted courtesy of SRI International, formerly Stanford Research Institute.

Typical Particle Sizes



Units, Scales and Orders of Magnitude

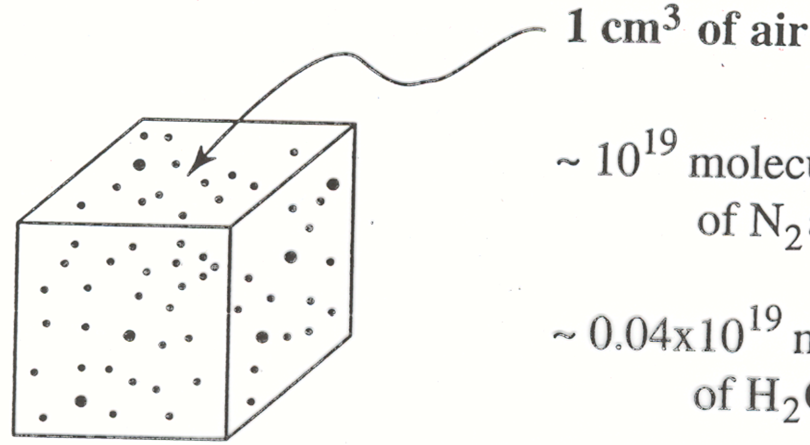
$$1\,\mu m = 10^{-4}\,cm$$

We will consider particles in the range:

$$0.001\,\mu m \text{ to } 10\,\mu m$$

(This is 4 orders of magnitude)

An Example



~ 10^{19} molecules of N_2 and O_2

~ 0.04×10^{19} molecules of H_2O

~ traces of other gases (ppm or ppb range)

~ $10^{-6} \times 10^{19}$ to $10^{-12} \times 10^{19}$ molecules/cc

~ ions

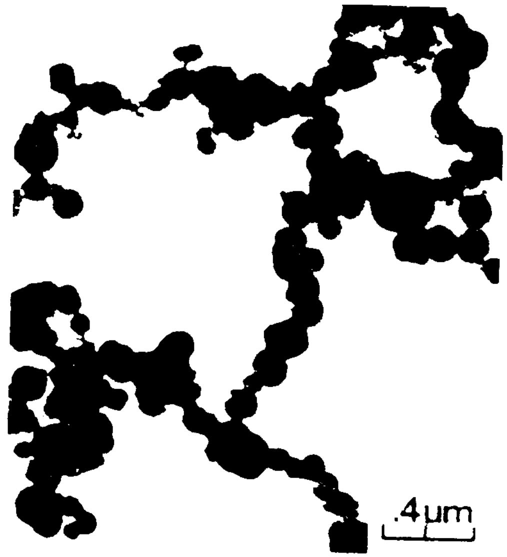
Consider one order of magnitude:

$0.001\mu m$

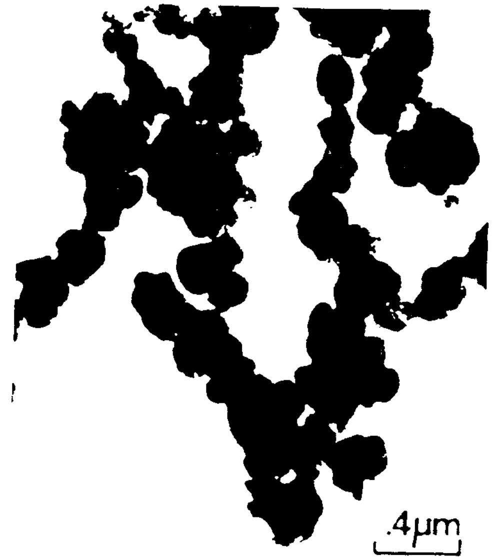
$\otimes$

$0.01\mu m$

$\otimes$

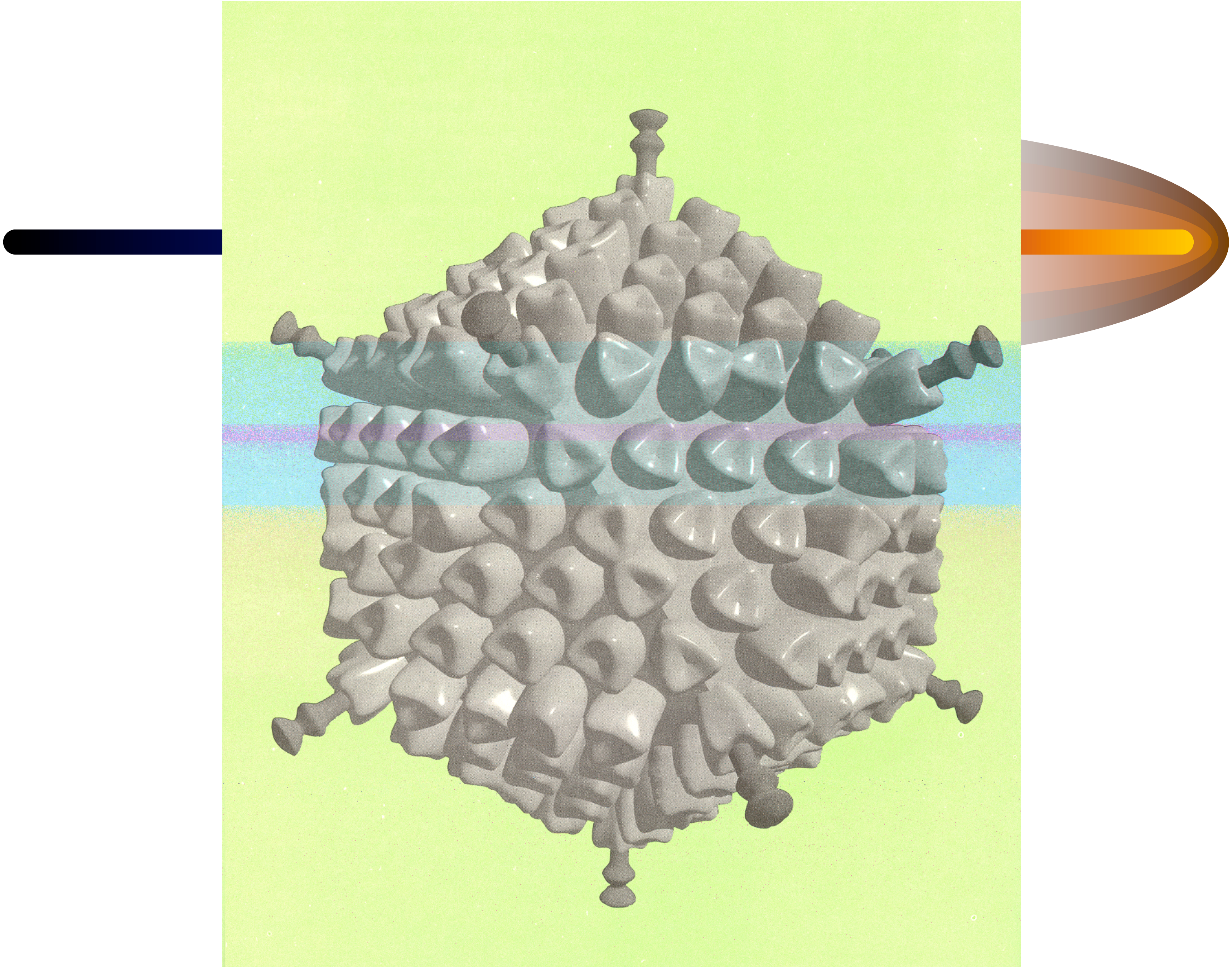


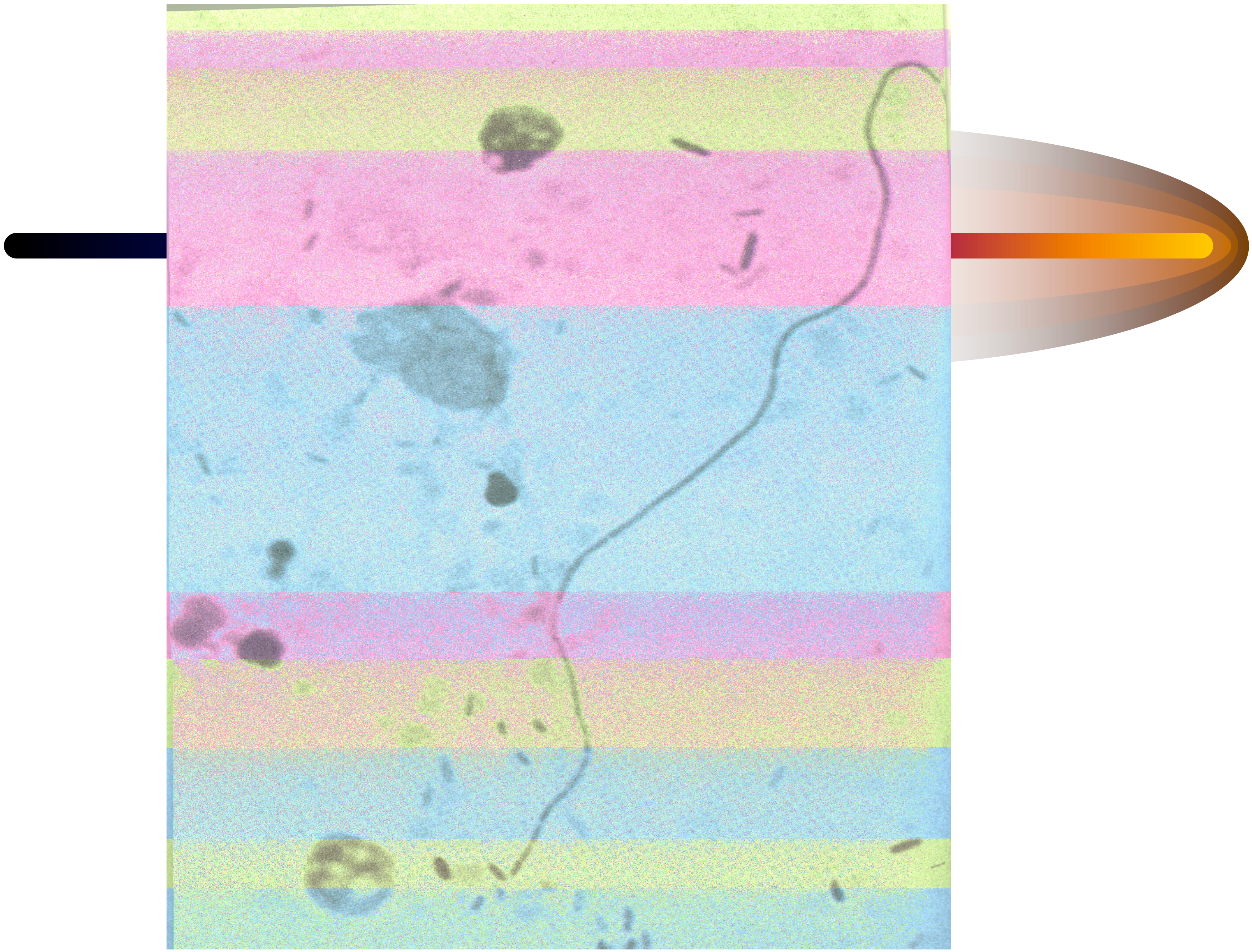
(a)

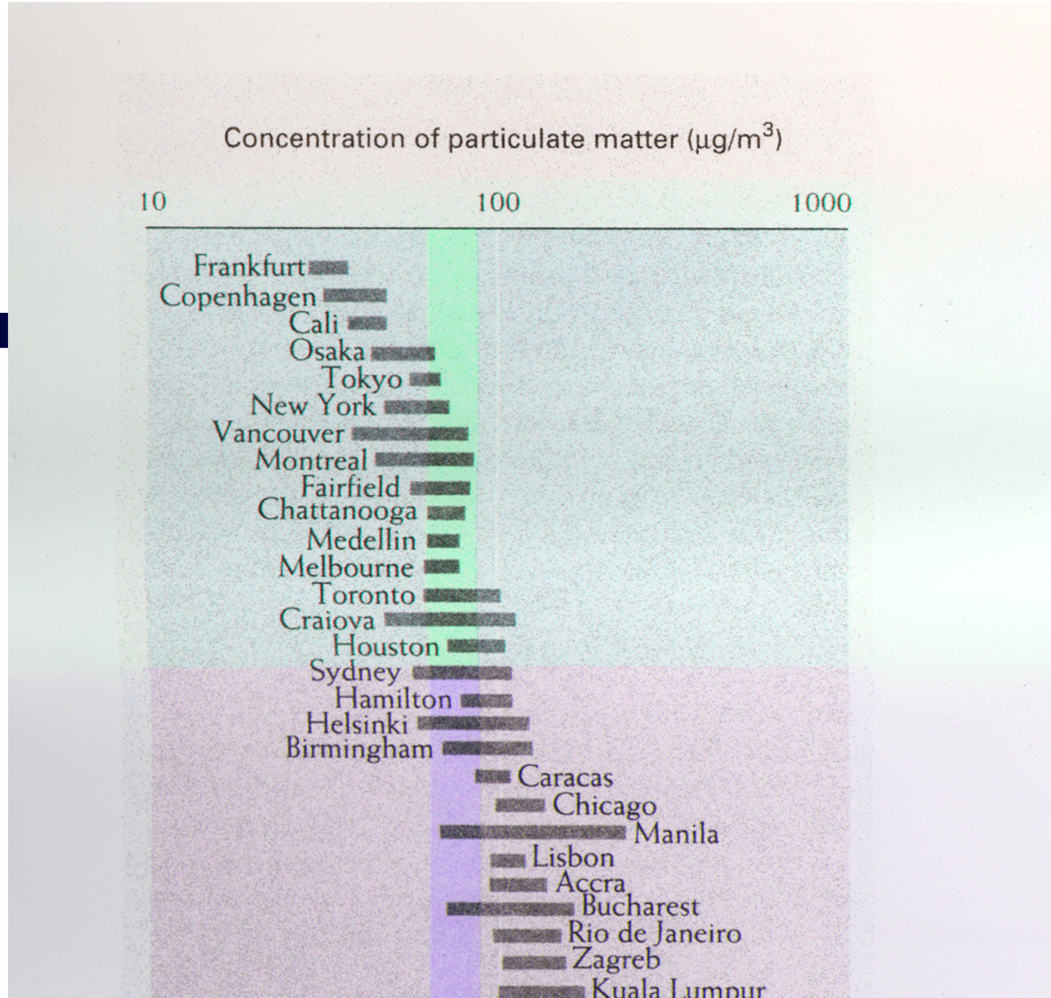


(b)

(c)





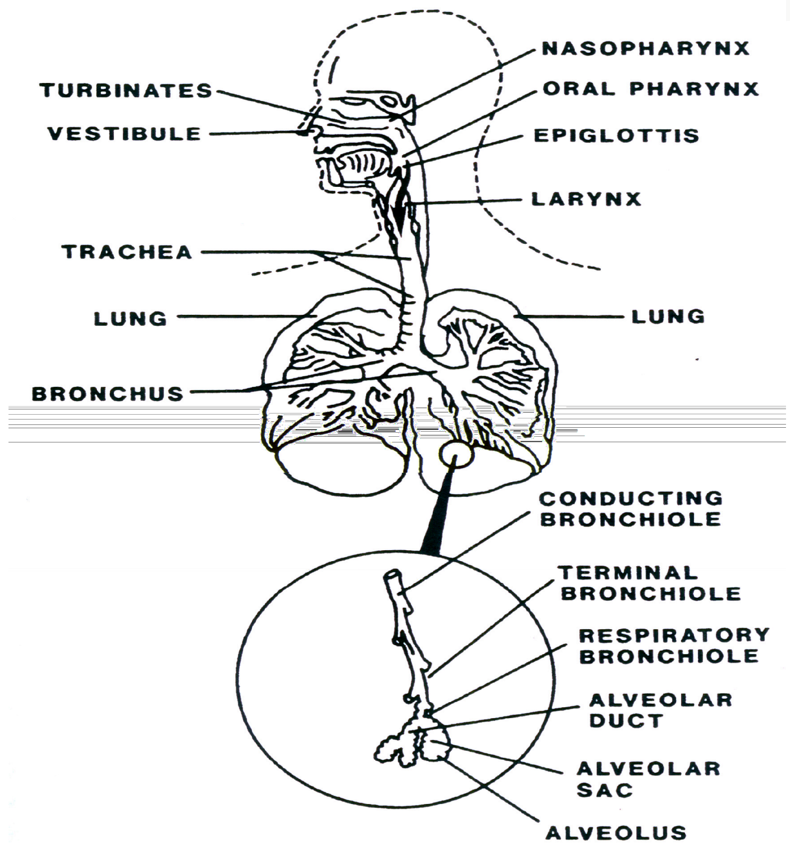


Concentration of particulate matter (µg/m3)
10
100
1000
Frankfurt
Copenhagen
Cali
Osaka
Tokyo
New York
Vancouver
Montreal
Fairfield
Chattanooga
Medellin
Melbourne
Toronto
Craiova
Houston
Sydney
Hamilton
Helsinki
Birmingham
Caracas
Chicago
Manila
Lisbon
Accra
Bucharest
Rio de Janeiro
Zagreb
Kuala Lumpur

Common Aerosol Properties

- Large residence times
- Large surface/volume ratio
- Complex Compositions
- Complex Shapes
- Sizes: 0.001 to 50 microns
- Interaction with light/radiation

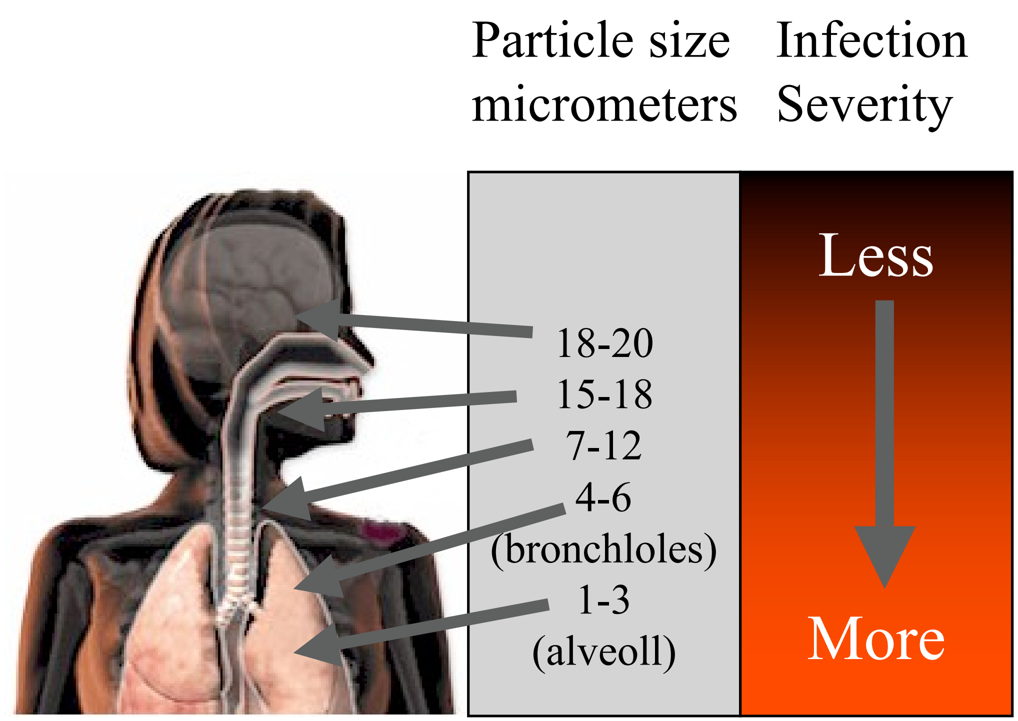
Human Respiratory Tract



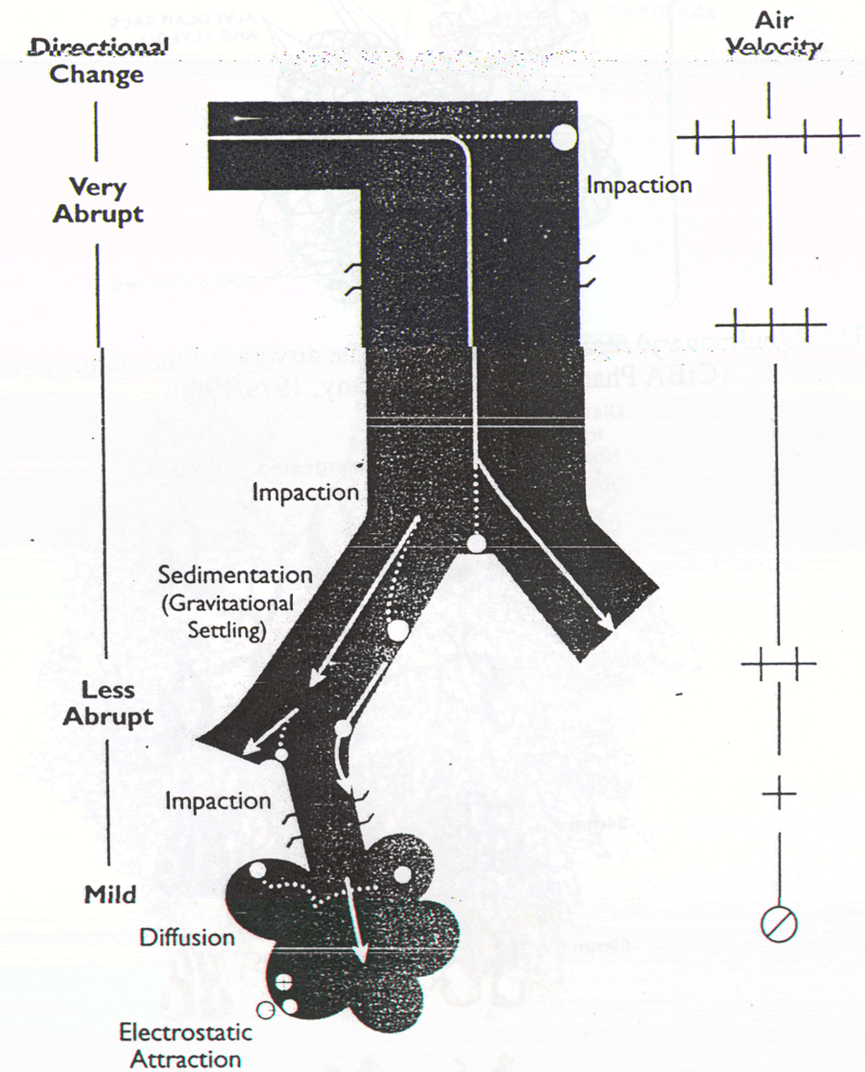
Aerosol Infectivity Relationship

Ideal aerosols would have a homogeneous population of 2-3 micron particles

Maximum infection of the human respiratory system are with particles between 1-3 microns size

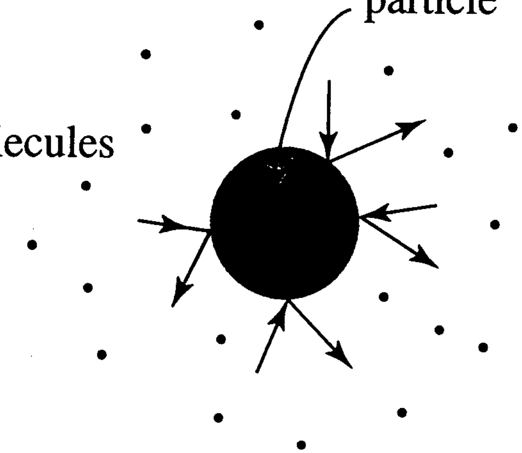


Schematic Representation of Four Major Mechanisms Causing Particle Deposition



Airflow is signified by arrows, particle trajectories by dashed lines.

Diffusion of Particles (The Brownian Motion)



Fluctuations in momentum transfer by individual molecules to the particle lead to random motion of the particle.

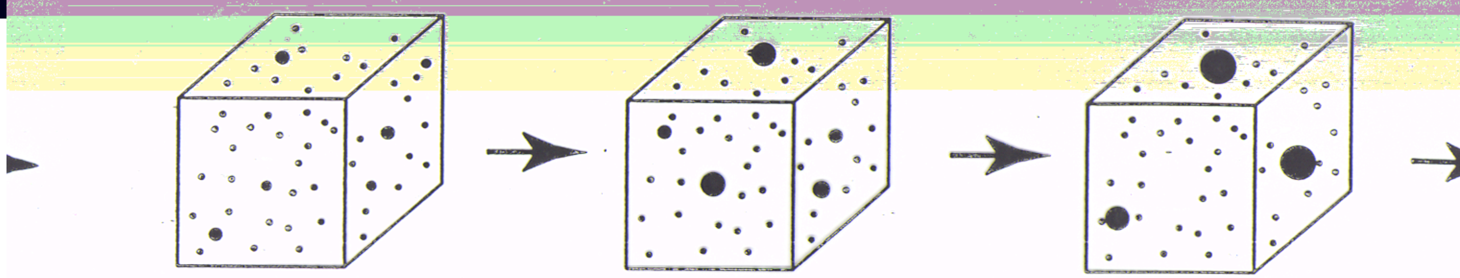
Einstein (1905):

$$\overline{x^2} = 2Dt$$

Aerosol properties as a function of size of a unit density sphere in air at Standard Temperature and Pressure (STP).

Particle Diameter (μm) d_p	Sedimentation Velocity (cm/sec) $V_s = \frac{m\,g\,C_c}{3\pi\,\mu\,d_p}$	Diffusion Coefficient (cm^2/sec) $D = B\,k\,T$	Mobility (sec/gm) $B = \frac{V_s}{m\,g}$	Particle Relaxation Time (sec) $\tau = m\,B$
0.001	6.5530E–07	5.1084E–02	1.2719E+12	6.6595E–10
0.01	6.6901E–06	5.2312E–04	1.3025E+10	6.8197E–09
0.1	8.6316E–05	6.7494E–06	1.6804E+08	8.7988E–08
1.0	3.5054E–03	2.7410E–07	6.8245E+06	3.5733E–06
10.0	3.0605E–01	2.3931E–08	5.9583E+05	3.1198E–04
100.0	2.4844E+01	2.3583E–09	5.8717E+04	3.0744E–02

Evolution of a Particulate (Aerosol) System

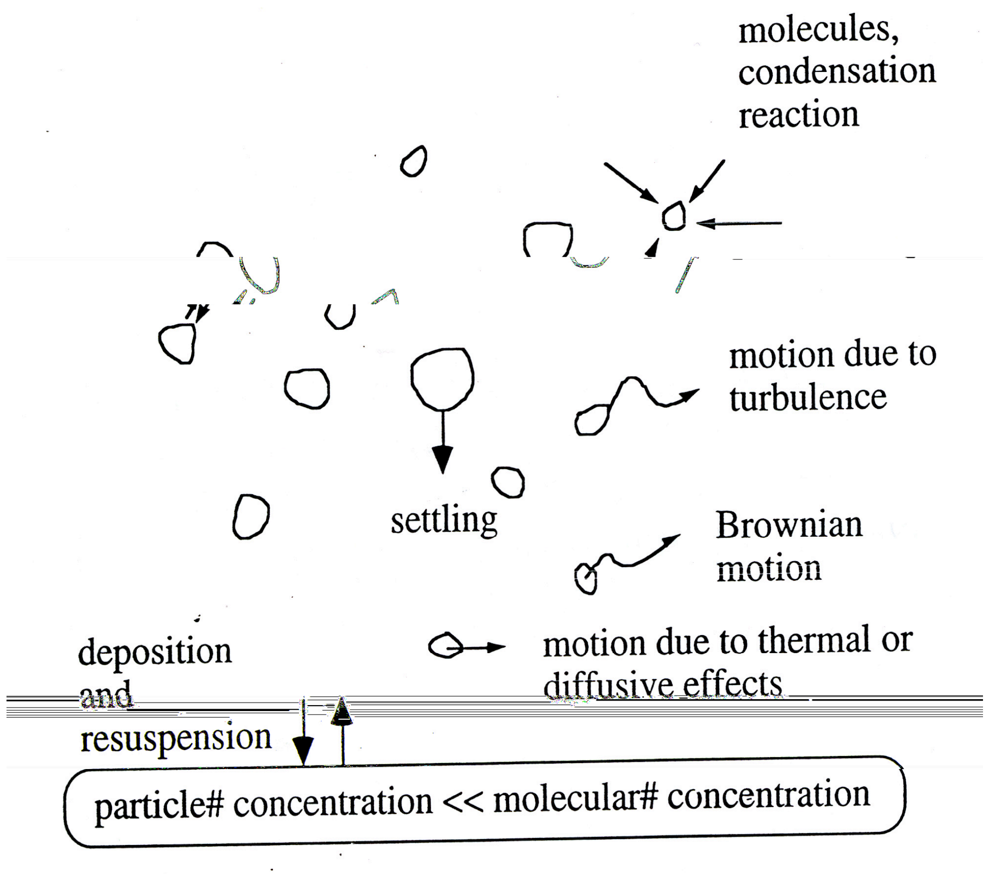


t = 0 t = 1 sec t = 2 secs

There are both sources and sinks of molecules and particles in the system.

Also, molecules and particles intra-act and interact amongst themselves and with surfaces.

Aerosol Interaction and Dynamics



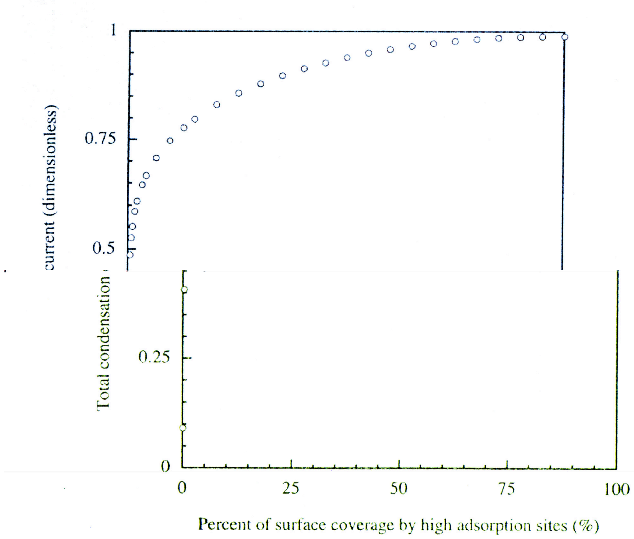
molecule-molecule
molecule-particle
particle-particle
particle-system

(also interactions with sunlight, etc.)

Processes

- Condensation/Evaporation
- Coagulation
- Interaction with light
- Particle formation (nucleation)
- Particle charging
- Surface Chemistry
- Intraparticle reactions
- &
- Thermodynamics
- etc.

A spherical particle with alternating high and low adsorption sites.



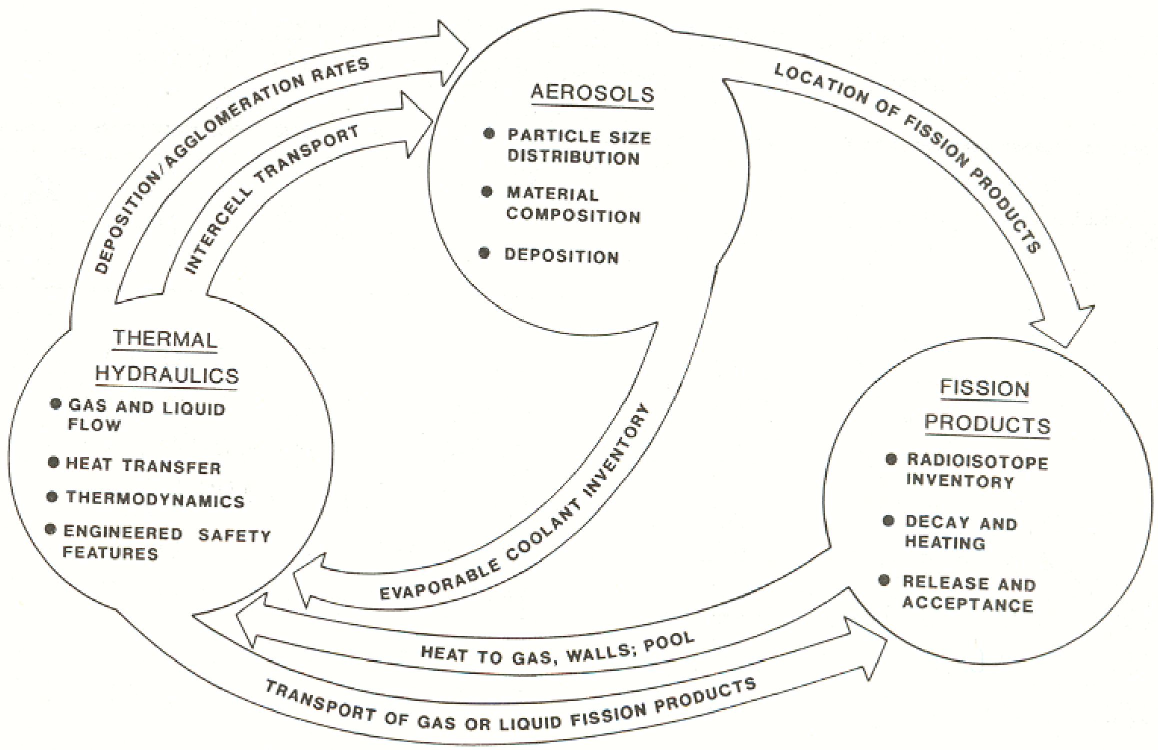
Total condensation rate on the particle as a function of coverage by adsorption sites

Practical Approach

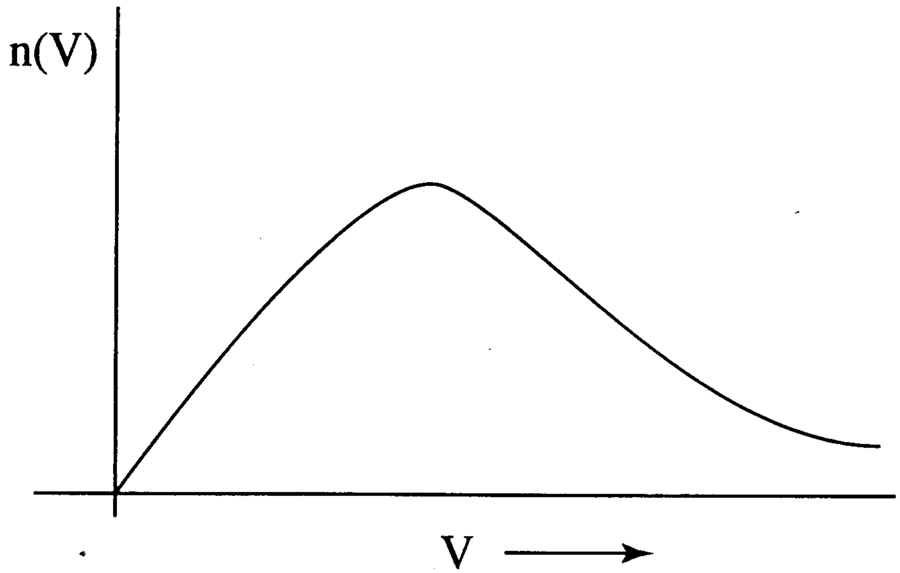
Divide and Conquer

(That is, consider phenomena at different length and time scales separately, and then develop an overall approximate description of the full system)

Modules in CONTAIN



Particle Size Distribution



$n(V)\,\mathrm{d}V$: "Expected" # of particles of volume V in $\mathrm{d}V/\mathrm{cm}^3$

Aerosol Transport Equation

$$\frac{\partial}{\partial t} n(\mathbf{v},\mathbf{m},t) + R(\mathbf{v},\mathbf{m},t)\, n(\mathbf{v},\mathbf{m},t) + \sum_{p=1}^{N} \frac{\partial}{\partial v_p}\left[I_p(\mathbf{v},\mathbf{m},t)\, n(\mathbf{v},\mathbf{m},t) \right]$$

$$= \frac{1}{2}\int_0^\infty d\mathbf{u} \int_0^\infty d\mathbf{w} \int_0^\infty d\mathbf{q} \int_0^\infty d\mathbf{s}\; n(\mathbf{u},\mathbf{q},t)\, n(\mathbf{w},\mathbf{s},t)\, K(\mathbf{u},\mathbf{q}\,|\,\mathbf{w},\mathbf{s})$$

$$\times \prod_{p=1}^{N} \delta\left(v_p - u_p - w_p\right) \delta\left(m_p - q_p - s_p\right)$$

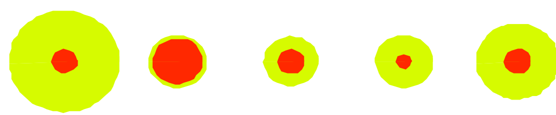
$$- n(\mathbf{v},\mathbf{m},t) \int_0^\infty d\mathbf{u} \int_0^\infty d\mathbf{q}\; K(\mathbf{u},\mathbf{q}\,|\,\mathbf{v},\mathbf{m})\, n(\mathbf{u},\mathbf{q},t) + S(\mathbf{v},\mathbf{m},t)$$

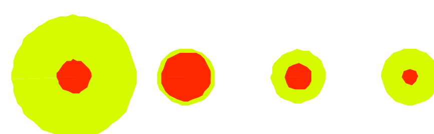
$$
\begin{aligned}
\frac{dQ_{\ell k}(t)}{dt} = {} & \frac{1}{2}\sum_{i=1}^{\ell-1}\sum_{j=1}^{\ell-1}\left(\overline{K}^{(1a)}_{ij\ell}\, Q_{jk}(t)\, Q_i(t) + \overline{K}^{(1b)}_{ij\ell}\, Q_{ik}(t)\, Q_j(t)\right) \\
& -\sum_{i=1}^{\ell-1}\left[\overline{K}^{(2a)}_{i\ell} Q_i(t)\, Q_{\ell k}(t) - \overline{K}^{(2b)}_{i\ell} Q_\ell(t)\, Q_{ik}(t)\right] \\
& -\frac{1}{2}\overline{K}^{(3)}_{\ell\ell} Q_\ell(t)\, Q_{\ell k}(t) - Q_{\ell k}(t)\sum_{i=\ell+1}^{m}\overline{K}^{(4)}_{i\ell}\, Q_i(t) \\
& +\overline{G}^{(1)}_{\ell k} Q_\ell(t) - \sum_{i=1}^{N_a}\left[\overline{G}^{(2)}_{\ell i}\, Q_{\ell k}(t) - \overline{G}^{(2)}_{\ell-1,i}\, Q_{\ell-1,k}(t)\right] \\
& +\overline{G}^{(3)}_{\ell-1,k} Q_{\ell-1}(t) + \overline{S}_{\ell k}(t) - Q_{\ell k}(t)\sum_{j=1}^{N_{str}}\overline{R}_{j\ell}(t)
\end{aligned}
$$

Natural effects not considered

- Charge
- Radioactivity
- Shape
- Spatial imhomogeneity
- Particle viability (not a factor for nuclear aerosols)
- Many reactions

Two Component Aerosol





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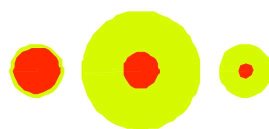

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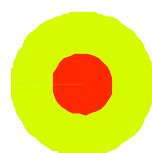
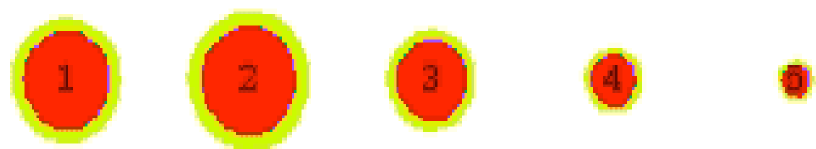



1
2
3
4

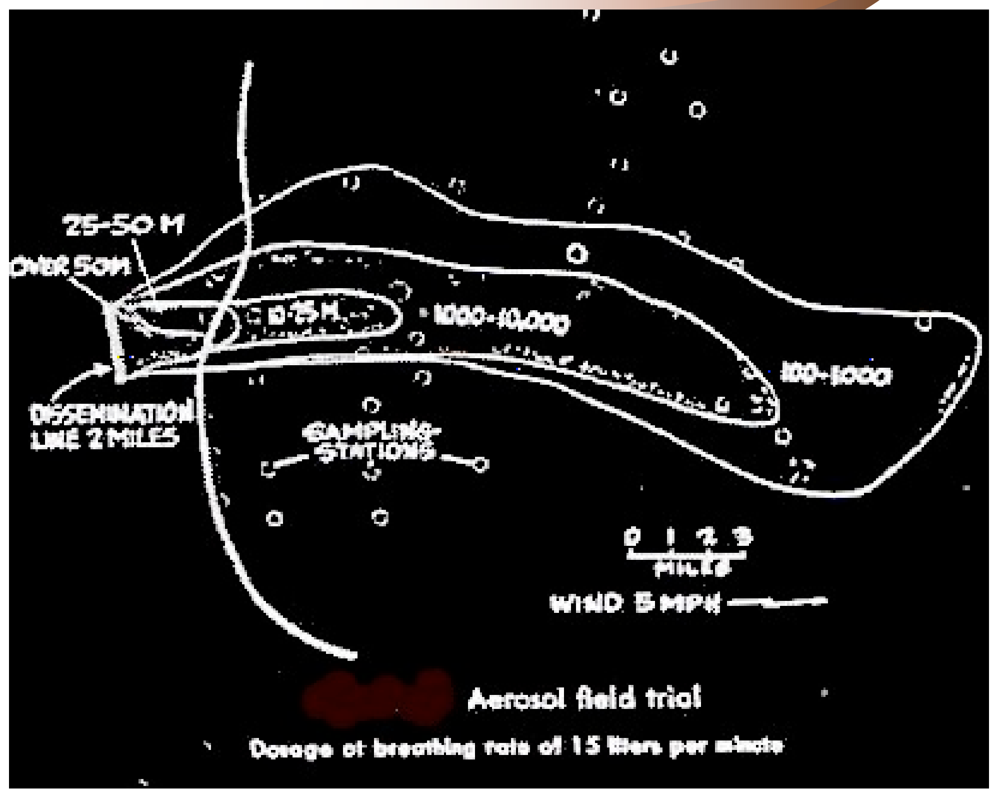
Infectious agents most effective when spread in an aerosol form

Disease	Transmit Man to Man	Infective Dose (Aerosol)
Inhalation anthrax	No	8,000-50,000 spores
Brucellosis	No	10 -100 organisms
Cholera	Rare	10-500 organisms
Glanders	Low	Assumed low
Pneumonic Plague	High	100-500 organisms
Tularemia	No	10-50 organisms
Q Fever	Rare	1-10 organisms
Smallpox	High	Assumed low (10-100 organisms)
Venezuelan Equine Encephalitis	Low	10-100 organisms
Viral Hemorrhagic Fevers	Moderate	1-10 organisms
Botulism	No	0.001 mg/kg is LD_{50} for type A
Staph Enterotoxin B	No	0.03 mg/person incapacitation
Ricin	No	3-5 mg/kg is LD_{50} in mice
T-2 Mycotoxins	No	Moderate

Lethal Dose Amount of Agent (in Kilograms) to produce 50% Casualties on 1 Square Kilometer Target

Type	Agent	Kilograms
Biological	Anthrax	0.09
Biological	SEB	119
Biological	Botulinum	345
Biological	Ricin	1,727
Chemical	VX	5,000
Chemical	Mustard	10,000
Nuclear	Fission	13,333

1956 Release of Bacillus Globigii (BG) Aerosol



Criteria For Biological Agents

- Easily and rapidly produced
- Can be made into 1 to 5 micrometer aerosol
- Can be concentrated and dried
- Are environmentally stable
  - Heat, air, humidity, UV
- Can be weaponized

Anthrax

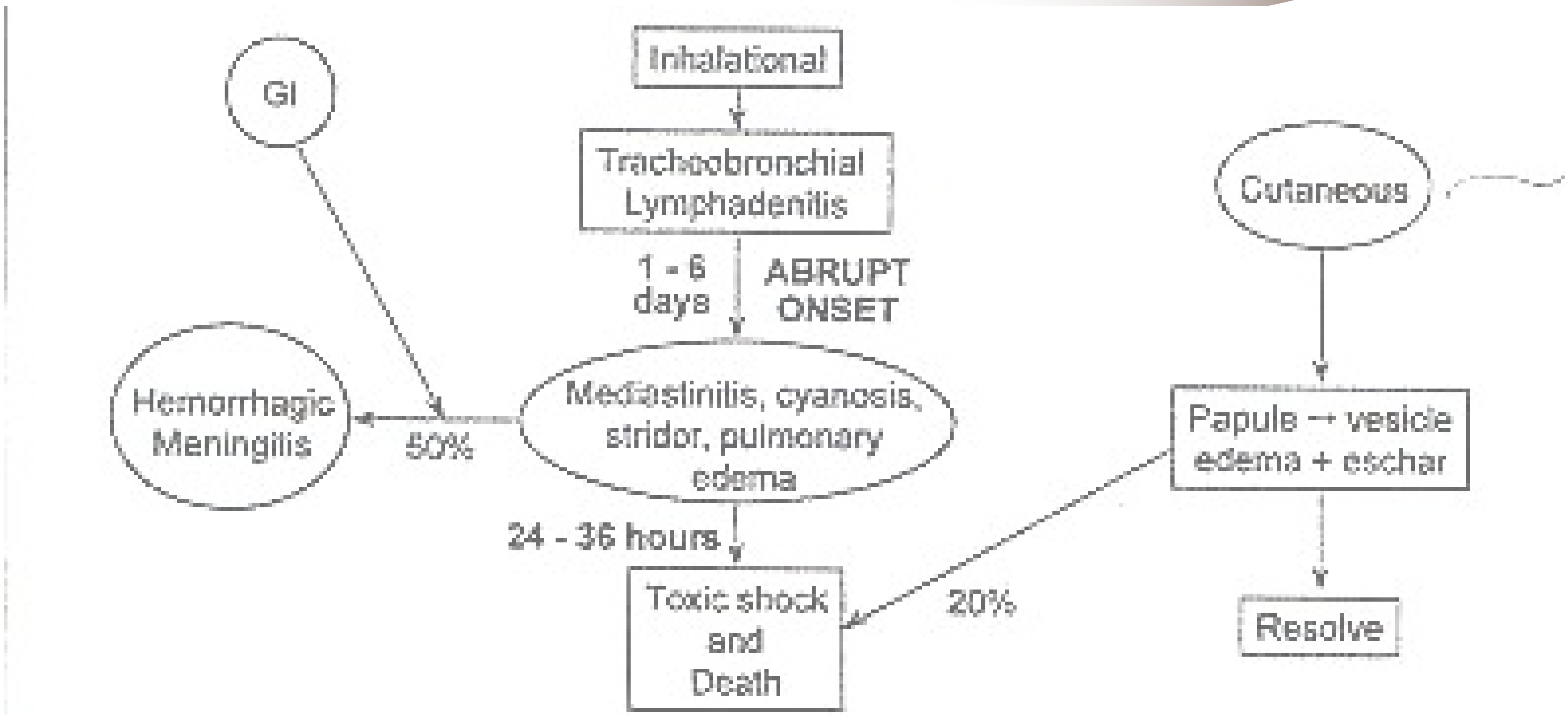
- Anthrax is stable to air, UV, and temperature. It forms spores and they can last for years.
- Anthrax can be introduced by ingestion (GI), inhaled, and through a cut in the skin.
- The most deadly is inhalation.
  - Spores go the regional lymph nodes
  - Two lethal toxins are produced.
    - Toxins kill cells

Inhalation Anthrax

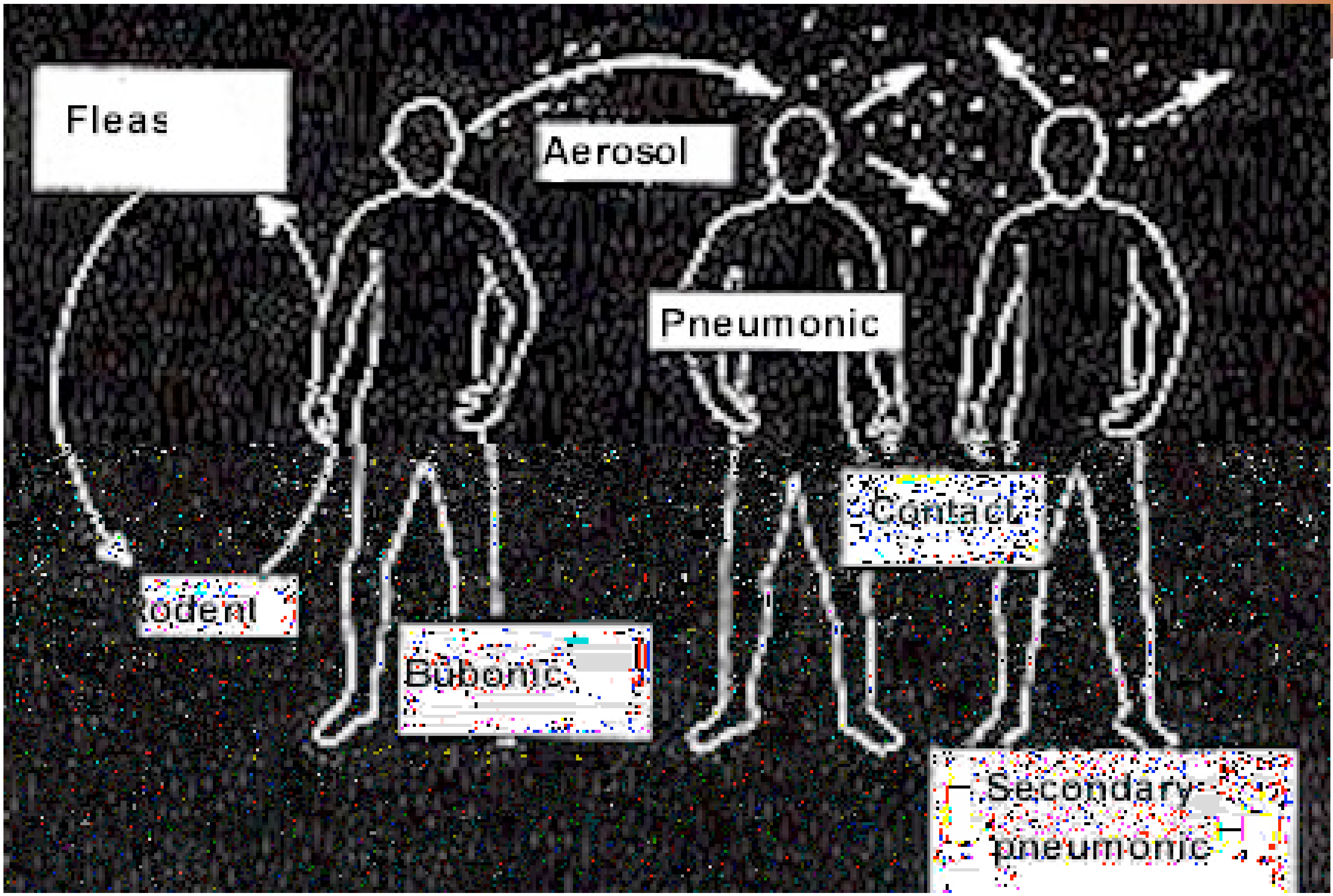
- Need about 10,000 spores to infect.
- Starts out like a flu
  - Dry cough and you do not feel well
- Initial improvement followed by an abrupt onset of respiratory distress and shock.

Note: If you are not treated before the abrupt onset of respiratory distress, then no treatment will work.

Anthrax Pathway



Methods of Transmission



Smallpox

- DNA virus
- Spread by aerosols
- Very stable as biological aerosol
- Resistant to common disinfectants
- Highly contagious
- Infectious until scabs are healed over
- A similar disease is Monkey Pox

Domestic Terrorism

- Consider an attack on a large skyscraper
  - Volume of structure is 1×10^{10} liters
  - Floor Area = 2.72 km^2

Amount of Material Required to Attack the Skyscraper

Agent	LD_{50} kg/km^2	Kg for Attack
Anthrax	0.06	0.1632
SEB	119	324
Botulinum	345	938
Ricin	1,727	4,698
VX	5,000	13,600
Mustard	10,000	27,200

Conclusions

1. Aerosol dispersion can be very effective

2. Aerosols are characterized by a few basic properties

3. Aerosol dynamics can be very complicated-direct as well as inverse problems